

High-Temperature Probe Station For Use In Microwave Device Characterization Through 500°C

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Abstract

A high-temperature measurement system capable of performing on-wafer microwave testing of semiconductor devices has been developed. This high temperature probe station can characterize active and passive devices and circuits at temperatures ranging from room temperature to above 500°C. The heating system uses a ceramic heater mounted on an insulating block of NASA shuttle tile material. The temperature is adjusted by a simple graphical computer interface and is automatically controlled by the software-based feedback loop. The system is used with a Hewlett-Packard 8510C Network Analyzer to measure scattering parameters over a frequency range of 1 to 50 GHz. The microwave probes, cables, and inspection microscope are all shielded to protect from heat damage. The high temperature probe station has been successfully used to characterize gold transmission lines on silicon carbide at temperatures up to 540°C.

Introduction

The ability to perform microwave tests at high temperatures is becoming necessary. There is now a need for sensors and communication circuits that operate at high temperatures (500°C and above) for aircraft engine development and monitoring during flight. To realize this need for high-temperature electronic systems, devices have been fabricated using wide bandgap semiconductors such as silicon carbide (SiC) with a targeted operating temperature of 500 to 600°C. However, the microwave properties of these devices often change drastically with temperature [1], so any designs that are intended to be used in such an environment must be characterized at high temperatures. It is possible to package the device under test (DUT) and characterize it in an oven, which is acceptable for some reliability, lifetime, and DC testing. However, for RF and microwave measurements, it is usually not possible to establish a calibrated reference plane at the DUT terminals within a package. In addition, the characteristics of the package will vary over a 500°C temperature range and would have to be accounted for during analysis of the data. A high-temperature probe station allows circuits and devices to be characterized through on-wafer measurements across a broad temperature range with a known reference plane.

Conventional, commercially available thermal wafer-probe stations are used to evaluate microwave devices across a controlled temperature range and have a typical upper limit of 200°C [2], [3]. Stand-alone thermal heating chucks are available with an extended upper temperature range of 300 to 400°C [4]. To effectively characterize devices at temperatures up to and surpassing 500°C, a custom probe station is needed. In the past, custom probe stations have been developed to test devices under other extreme environments, such as cryogenic temperatures as low as 37 K [5]. Similarly, a custom probe station specifically modified for high-temperature use allows devices to be measured quickly and flexibly, without the use of wire-bonds and test fixtures.

This paper describes a high-temperature probe station that is simple in design, but quite suitable for microwave characterization. A full description of the system is given, including heating stage, temperature controller, and probe shielding. Also presented is an example measurement of a Coplanar Waveguide (CPW) from room temperature through 540°C.

System Description

A photograph and a block diagram of the high temperature probe station are shown in Figure 1. The system consists of the ceramic heater mounted on NASA shuttle tile insulator, DC power supply, PC-based data acquisition and temperature controller, microwave probes, a microscope, and a network analyzer. In Figure 2, the probe station is shown making scattering parameter measurements from 1 to 50 GHz with a Hewlett-Packard 8510C Network Analyzer.

The heater is a Boralectric ceramic heater, model HT-05, produced by GE Advanced Ceramics and is rated to 1800°C. The heater is fixed atop a six-inch block of shuttle tile insulating material and DC power is supplied via the screw connections. The power supply is a Sorensen DCS 150-20 capable of sourcing 3 kW and is controlled via a General Purpose Interface Bus (GPIB) connection. At room temperature, the heater has a resistance of 24 Ω ; this value drops to 13 Ω at 500°C. To maintain a steady-state temperature of 500°C, the heater requires 150 watts of power, or a DC supply current of about 3.4 amps. A K-type thermocouple is mounted on the surface of the device under test to provide temperature readings to the laboratory computer. The heating stage can be brought up to 500°C in less than three minutes and will cool to a safe temperature of 50°C in less than ten minutes with no external cooling apparatus. The use of a small fan significantly speeds the cooling process, but was not used during DUT characterization.

Because of the intense heat radiated by the ceramic heater at temperatures above 300°C, a typical microwave probe cannot be used. A specially made high temperature probe by GGB Industries is used [6]. These GGB Industries Picoprobe ground-signal-ground (GSG) probes were manufactured with two custom modifications; a copper heat sink was affixed to the micro coax leading to the tungsten probe tips and reflective tape was added to the bottom of the probe body to help reduce the heating effects. As a further precaution for use at elevated temperatures, the authors have wrapped an

additional thin layer of shuttle tile insulator and a heavy foil heat shield around the probes, as shown in Figure 3. The UTiFLEX coaxial cables, manufactured by Micro-Coax, are also wrapped in a glass-fiber insulating sleeve and a foil heat shield and are connected to the microwave probes. Finally, a Pyrex shield is held in place to protect the microscope from radiated heat. All of these modifications are shown in Figures 1, 2, and 3.

To measure the temperatures around the probe station, the heater was held at a constant 500°C with one thermocouple. A second thermocouple was then moved around the instrument. The top of the SiC wafer registered 485°C, while the Pyrex glass shield protecting the microscope lens was 65°C. Temperatures were also measured on the bottom (160°C), side (90°C), and top (60°C) of the microwave probe shielding, as well as copper heatsink (120°C) and the connecting end of the coaxial cable (45°C), as shown in Figure 4. Throughout the high temperature tests, the shuttle tile block could be moved by hand and stayed cool to the touch.

The heating system is controlled from a Windows computer running National Instruments' LabView software. The computer is equipped with both a GPIB interface card to control the DC power supply and a NI4351 data acquisition card to collect thermocouple data. The LabView interface presents the user with the necessary readings, including heater temperature, power supply voltage and current, and length of test, as well as a real-time plot of temperature. The interface has options to run the heating system in both open- and closed-loop configurations and will record thermocouple temperatures, as well as the heater voltage and current, to a log file. The user needs only to enter the desired temperature. The software calculates the current to be supplied to the heater through a proportional-integral-differential (PID) feedback loop and transmits this information to the power supply via the GPIB interface. At low temperatures (under 200°C) the standard deviation of the controlled temperature is better than 0.5°C. At temperatures above 350°C, the standard deviation increases to a value that is typically between 0.8 and 1.2°C. A screen shot of the user interface is shown in Figure 5.

Measurement Example

A set of CPW lines were fabricated on a semi-insulating 4H-SiC wafer from Cree [7]. The metal lines consist of 1.5µm gold on top of 200Å titanium. The CPW lines have a center conductor width of 50µm, a slot width of 25µm, a ground plane width of 150µm, and lengths of 5000, 5850, 6700, 8500, and 17500µm, as well as a 2500µm reflective short. The network analyzer was calibrated at room temperature using these CPW standards and the NIST Multical software [8]. Measurements of two-port scattering parameters of the 17500µm line were then taken from room temperature to 540°C in intervals of 30°C. As a precaution, the probes were lifted between each raise in temperature and were set again after the temperature had stabilized. The magnitude and phase of S_{12} are shown in Figures 6 and 7.

From the measured magnitude of S_{12} , it is clear that the transmission line losses increase with frequency and temperature as expected. The phase of S_{12} decreases with the rising temperature, suggesting that the effective dielectric constant of the transmission line ($\epsilon_{eff} = 5.5$ at room temperature) is increasing slightly with temperature. The results are very consistent though 450°C, and show no effect of degradation of probes, cables, or the line under test. Above 480°C, the effects of repeated probing— the pads on the 17500µm line had been probed 18 times by this point— become apparent. More force was needed to ensure contact to the CPW pads, causing the last three measurements to scatter from the trend. This problem can be avoided by probing in larger intervals; probing in temperature increments of 50°C would cause significantly less damage to the probe pads.

Because calibration was only performed at room temperature, the effects of heating the microwave probes and cables needed to be removed from the measured data. The microwave probes were raised slightly above the heating surface, and the open-circuit reflection coefficient was measured as the heater was warmed from room temperature to 540°C. This procedure was then repeated with the probe tips shorted to a gold ground plane as the temperature was again swept. The results showed that the magnitude was consistent across temperature, varying less than 0.3 dB, while the phase increased as much as 18° relative to the room temperature measurement at high frequency and temperature (above 40 GHz and 500°C). The phase change due to heating the probes and cables was characterized as a function of frequency and temperature, and was used to correct the measured data.

The cables were also tested alone to determine their sensitivity to changes in temperature. The two thermally shielded cables were directly connected and suspended above the heater at a distance similar to the regular test setup. The heater temperature was again swept and S_{12} was recorded for the cable setup. During this test, the temperature of the warmest part of the cable never exceeded 50°C. The results show that the magnitude of S_{12} changes by less than 0.2 dB, while the phase decreases by less than 4°, at all frequencies and temperatures. Therefore, it is reasonable to assume that the bulk of the changes in the electrical properties of the system are due to heating in the microwave probes and not due to heating in the cables.

The microwave probes were inspected before and after use with a scanning electron microscope. Aside from minor misalignment, the probe tips appeared to be structurally sound. A small bit of residue had formed on the bottom side of the probes and the tips had discolored slightly at the highest temperatures. After the probe tips were cleaned and realigned, a second calibration proved to be successful. Pictures of the probe tips before use, after use, and after cleaning are shown in Figures 8 and 9.

Summary

A high-temperature probe station has been developed that is capable of testing microwave devices. The heating stage is well insulated from the probe station and heats

and cools quickly to facilitate measurements at various temperatures. The microwave probes and connectors are shielded from the heating element and have been demonstrated to withstand device temperatures as high as 540°C. The heating system is controlled from a simple computer interface, while a network analyzer is easily connected to the probe station to perform temperature dependent microwave measurements.

Acknowledgements

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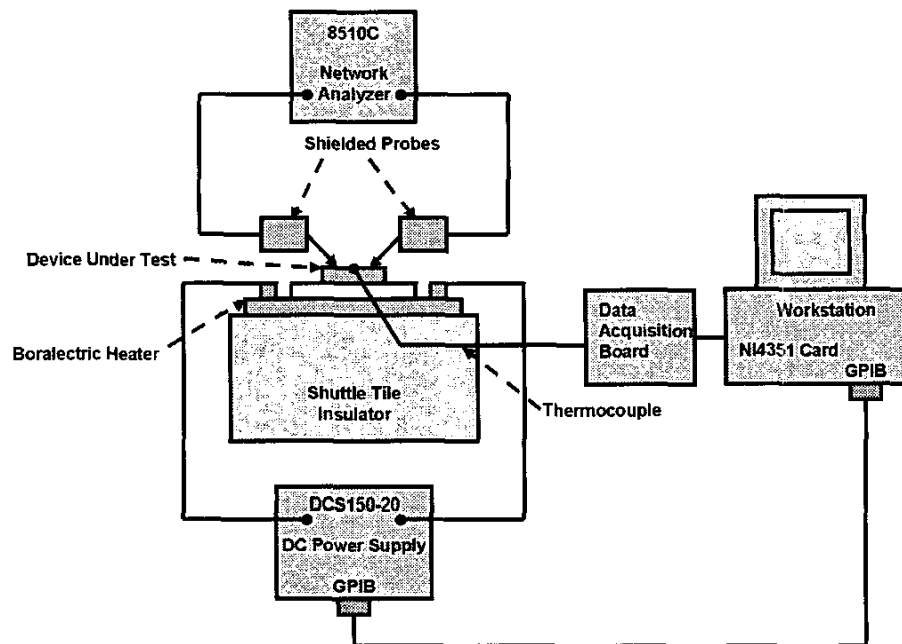
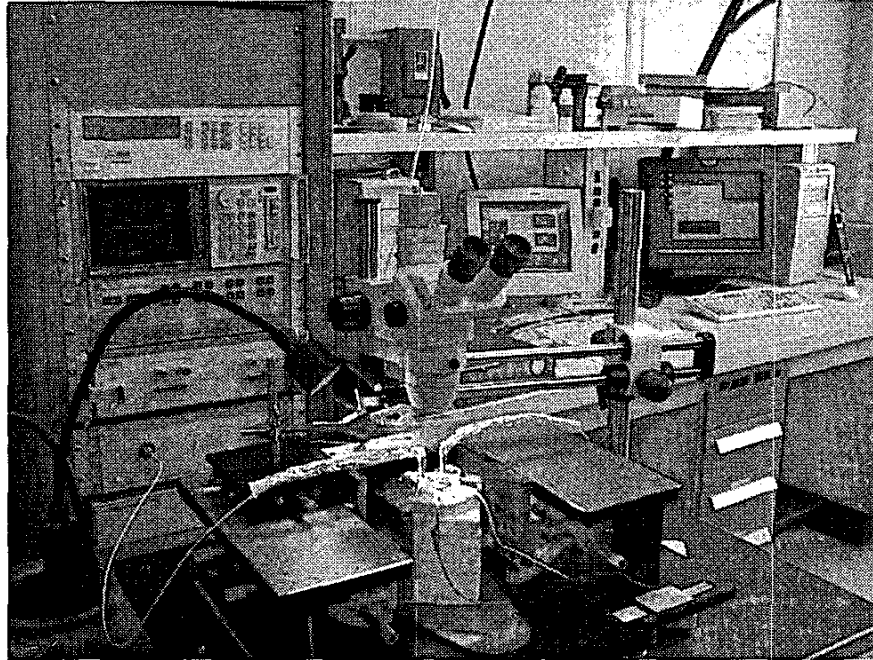


Figure 1. Photograph and block diagram of high-temperature probe station and instrumentation

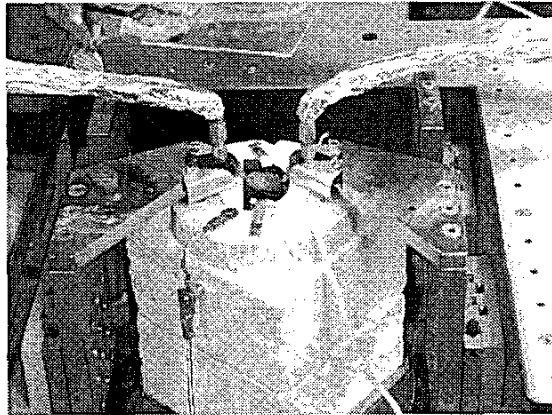


Figure 2. High-temperature probe station

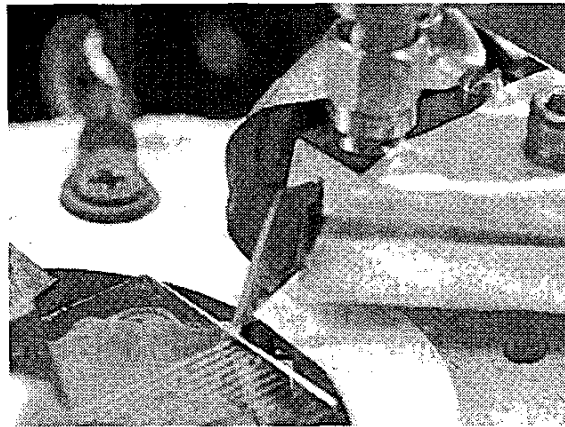


Figure 3. Microwave probe with heat shielding

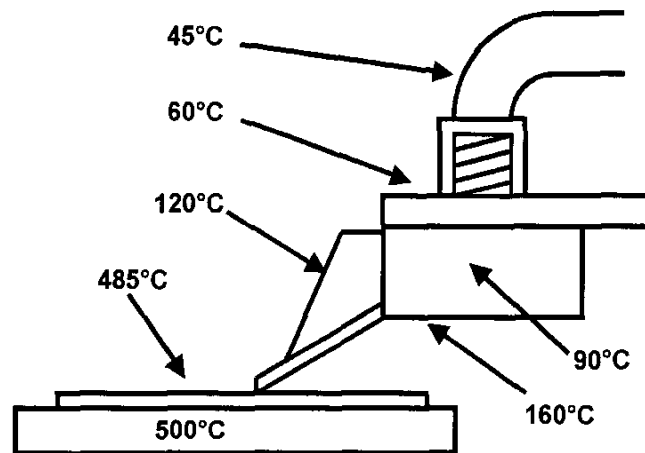


Figure 4. Local temperature values of the microwave probes and cables, with the heater at 500°C

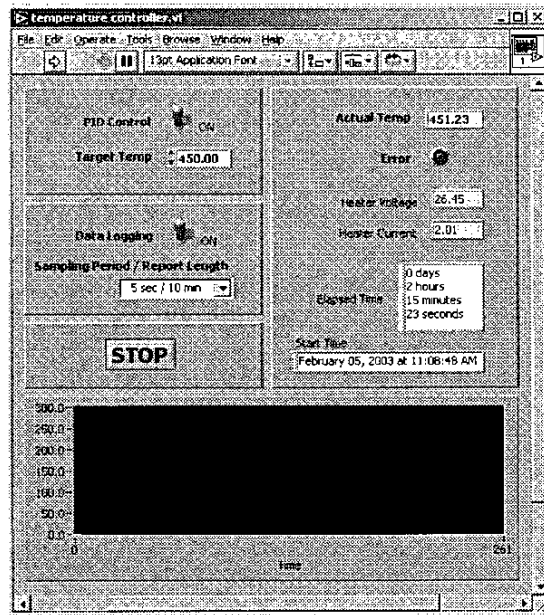


Figure 5. Temperature controller interface

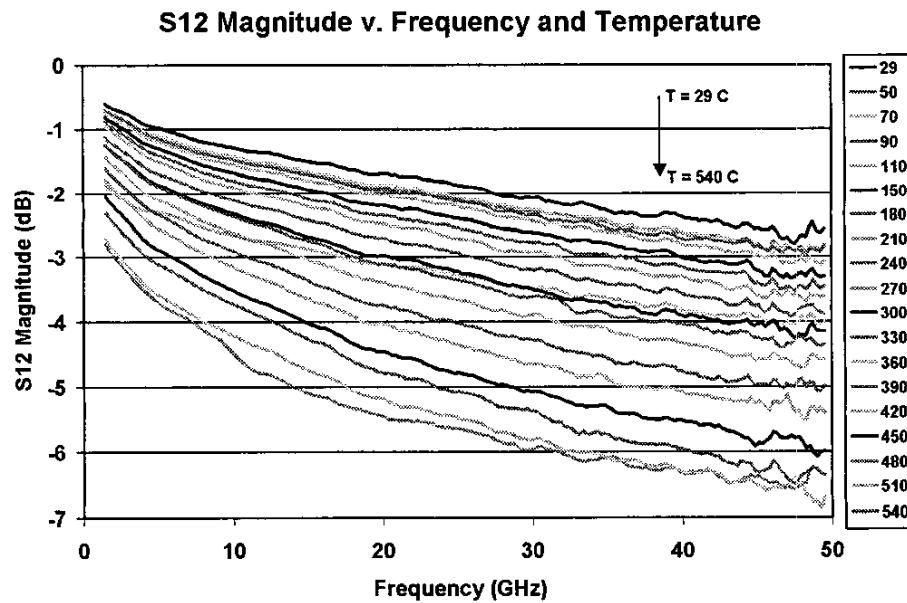


Figure 6. Measured magnitude of S_{12} for the 17500 μ m CPW line as a function of frequency at temperatures of 29 to 540°C

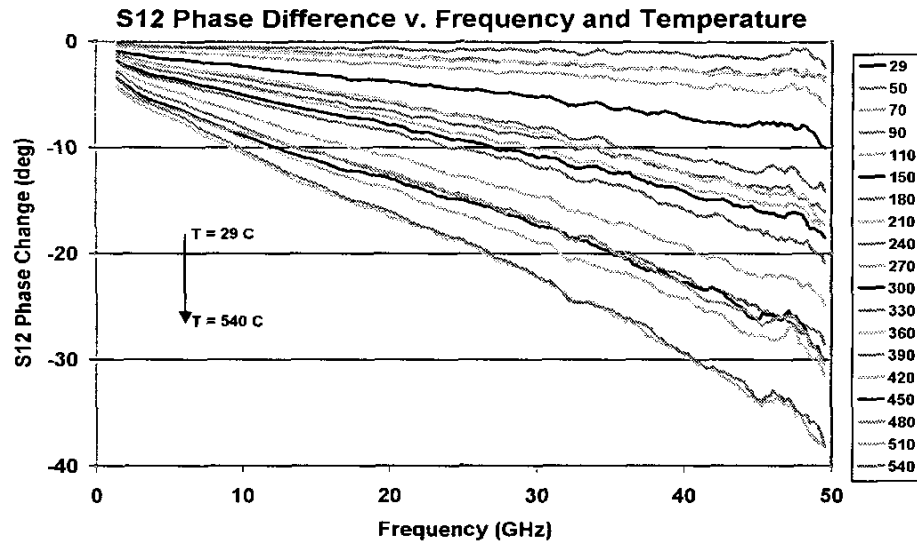


Figure 7. Measured change in phase of S_{12} , as compared to room temperature, for the 17500 μ m CPW line as a function of frequency at temperatures of 29 to 540°C

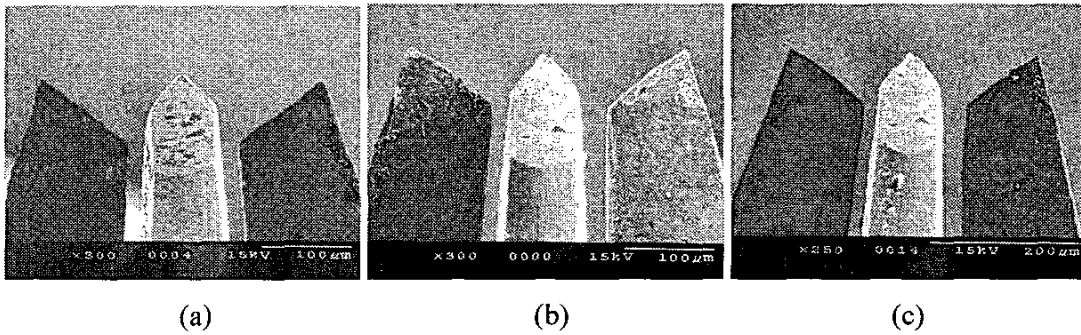


Figure 8. Scanning electron microscope pictures of the top side of the GSG wafer probes (a) before use, (b) after use at 540°C, and (c) after cleaning.

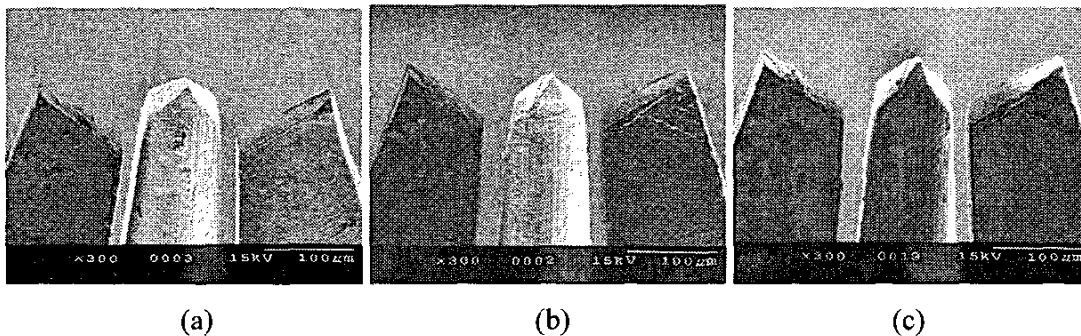


Figure 9. Scanning electron microscope pictures of the bottom side of the GSG wafer probes (a) before use, (b) after use at 540°C, and (c) after cleaning.